Date: 03/21/01 Express Mail Label No. EL 762238015 US

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Attorney's Docket No.: 2251.2007-000

ELECTRON BEAM EMITTER

BACKGROUND

A typical electron beam emitter includes a vacuum chamber with an electron generator positioned therein for generating electrons. The electrons are accelerated out from the vacuum chamber through an exit window in an electron beam. Typically, the exit window is formed from a metallic foil. The metallic foil of the exit window is commonly formed from a high strength material such as titanium in order to withstand the pressure differential between the interior and exterior of the vacuum chamber.

A common use of electron beam emitters is to irradiate materials such as inks and adhesives with an electron beam for curing purposes. Other common uses include the treatment of waste water or sewage, or the sterilization of food or beverage packaging. Some applications require particular electron beam intensity profiles where the intensity varies laterally. One common method for producing electron beams with a varied intensity profile is to laterally vary the electron permeability of either the electron generator grid or the exit window. Another method is to design the emitter to have particular electrical optics for producing the desired intensity profile. Typically, such emitters are custom made to suit the desired use.

SUMMARY

The present invention is directed to an exit window for an electron beam emitter through which electrons pass in an electron beam. For a given exit window foil thickness, the exit window is capable of withstanding higher intensity electron beams than currently available exit windows. In addition, the exit window is capable of operating in corrosive environments. The exit window of the present invention includes an exit window foil having an interior and an exterior surface. A corrosion resistant layer having high thermal conductivity is formed over the exterior surface of the exit window foil for resisting corrosion and increasing thermal conductivity. The increased thermal conductivity allows heat to be drawn away from the exit window foil more rapidly so that the exit window foil is able to handle electron beams of higher intensity which would normally burn a hole through the exit window.

In preferred embodiments, the exit window foil and the corrosion resistant layer each have a thickness. Typically, the exit window foil is formed from titanium about 6 to 12 microns thick. In one embodiment, the corrosion resistant layer is formed from diamond about .25 to 2 microns thick. In another embodiment, the corrosion resistant layer is formed from gold about .1 to 1 microns thick. The thickness of the corrosion resistant layer is commonly about 4% to 8% the thickness of the exit window foil. The corrosion resistant layer is usually formed by vapor deposition with a material having a density above .1 lb./in.^{3} and thermal conductivity above 300 W/m·k.

The present invention is also directed to an electron beam emitter including a vacuum chamber with an electron generator positioned within the vacuum chamber for generating electrons. The vacuum chamber has an exit window through which the electrons exit the vacuum chamber in an electron beam. The exit window includes an exit window foil having an interior and exterior surface. A corrosion resistant layer having high thermal conductivity is formed over the exterior surface of the exit window foil for resisting corrosion and increasing thermal conductivity.

In the present invention, by providing an exit window for an electron beam emitter which has increased thermal conductivity, thinner exit window foils are possible. Since less power is required to accelerate electrons through thinner exit window foils, an electron beam emitter having such an exit window is able to operate more efficiently (require less power) for producing an electron beam of a particular intensity. Alternatively, for a given foil thickness, the high thermal conductive layer allows the exit window in the present invention to withstand higher power than previously possible for a foil of the same thickness to produce a higher intensity electron beam. Furthermore, the corrosion resistant layer allows the exit window to be exposed to corrosive environments while operating.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a schematic sectional drawing of an electron beam emitter of the present invention.

FIG. 2 is a side view of a portion of the electron generating filament.

FIG. 3 is a side view of a portion of the electron generating filament depicting one method of forming the filament.

FIG. 4 is a side view of a portion of another embodiment of the electron generating filament.

FIG. 5 is a cross sectional view of still another embodiment of the electron generating filament.

FIG. 6 is a side view of a portion of the electron generating filament depicted in FIG. 5.

FIG. 7 is a side view of a portion of yet another embodiment of the electron generating filament.

FIG. 8 is a top view of another electron generating filament.

FIG. 9 is a top view of still another electron generating filament.

FIG. 10 is a cross sectional view of a portion of the exit window.

DETAILED DESCRIPTION

Referring to FIG. 1, electron beam emitter 10 includes a vacuum chamber 12 having an exit window 32 at one end thereof. An electron generator 20 is positioned within the interior 12a of vacuum chamber 12 for generating electrons e^- which exit the vacuum chamber 12 through exit window 32 in an electron beam 15. In particular, the electrons e^- are generated by an electron generating filament assembly 22 positioned within the housing 20a of the electron generator 20 and having one or more electron generating filaments 22a. The bottom 24 of housing 20a includes series of grid-like openings 26 which allow the electrons e^- to pass therethrough. The cross section of each filament 22a is varied (FIG. 2) to produce a desired electron generating profile. Specifically, each filament 22a has at least one larger or major cross sectional area portion 34 and at least one smaller or minor cross sectional area portion 36, wherein the cross sectional area of portion 34 is greater than that of portion 36. The housing 20a and filament assembly 22 are electrically connected to high voltage power supply 14 and filament power supply 16, respectively, by lines 18a and 18b. The exit window 32 is electrically grounded to impose a high voltage potential between housing 20a and exit window 32, which accelerates the electrons e^- generated by electron generator 20 through exit window 32. The exit window 32 includes a structural metallic foil 32a (FIG. 10) that is sufficiently thin to allow the passage of electrons e^- therethrough. The exit window 32 is supported by a rigid support plate 30 that has holes 30a therethrough for the passage of electrons e^-. The exit window 32 includes an exterior coating or layer

32b of corrosion resistant high thermal conductive material for resisting corrosion and increasing the conductivity of exit window 32.

In use, the filaments 22a of electron generator 20 are heated up to about 4200° F by electrical power from filament power supply 16 (AC or DC) which causes free electrons e^- to form on the filaments 22a. The portions 36 of filaments 22a with smaller cross sectional areas or diameters typically have a higher temperature than the portions 34 that have a larger cross sectional area or diameter. The elevated temperature of portions 36 causes increased generation of electrons at portions 36 in comparison to portions 34. The high voltage potential imposed between filament housing 20a and exit window 32 by high voltage power supply 14 causes the free electrons e^- on filaments 22a to accelerate from the filaments 22a out through the openings 26 in housing 20a, through the openings 30a in support plate 30, and through the exit window 32 in an electron beam 15. The intensity profile of the electron beam 15 moving laterally across the electron beam 15 is determined by the selection of the size, placement and length of portions 34/36 of filaments 22a. Consequently, different locations of electron beam 15 can be selected to have higher electron intensity. Alternatively, the configuration of portions 34/36 of filaments 22a can be selected to obtain an electron beam 15 of uniform intensity if the design of the electron beam emitter 10 normally has an electron beam 15 of nonuniform intensity.

The corrosion resistant high thermal conductive coating 32b on the exterior side of exit window 32 has a thermal conductivity that is much higher than that of the structural metallic foil 32a of exit window 32 . The coating 32b is sufficiently thin so as not to substantially impeded the passage of electrons e^- therethrough but thick enough to provide exit window 32 with a thermal conductivity much greater than that of foil 32a. When the structural foil 32a of an exit window is relatively thin (for example, 6 to 12 microns thick), the electron beam 15 can burn a hole through the exit window if insufficient amounts of heat is drawn away from the exit window. Depending upon the

material of foil 32a and coating 32b, the addition of coating 32b can provide exit window 32 with a thermal conductivity that is increased by a factor ranging from about 2 to 8 over that provided by foil 32a, and therefore draw much more heat away than if coating 32b was not present. This allows the use of exit windows 32 that are thinner than would normally be possible for a given operating power without burning holes therethrough. An advantage of a thinner exit window 32 is that it allows more electrons e^- to pass therethrough, thereby resulting in a higher intensity electron beam 15 than conventionally obtainable. Conversely, a thinner exit window 32 requires less power for obtaining an electron beam 15 of a particular intensity and is therefore more efficient. By forming the conductive coating 32b out of corrosion resistant material, the exterior surface of the exit window 32 is also made to be corrosion resistant and is suitable for use in corrosive environments.

Sub A1) A more detailed description of the present invention now follows. FIG. 1 generally depicts electron beam emitter 10. The exact design of electron beam emitter 10 may vary depending upon the application at hand. Typically, electron beam emitter 10 is similar to those described in U.S. Patent Application Serial Nos. 09/349,592 (6467492) filed July 9, 1999 and 09/209,024 filed December 10, 1998, the contents of which are incorporated herein by reference in their entirety. If desired, electron beam emitter 10 may have side openings on the filament housing as shown in FIG. 1 to flatten the high voltage electric field lines between the filaments 22a and the exit window 32 so that the electrons exit the filament housing 20a in a generally dispersed manner. In addition, support plate 30 may include angled openings 30a near the edges to allow electrons to pass through exit window at the edges at an outwardly directed angle, thereby allowing electrons of electron beam 15 to extend laterally beyond the sides of vacuum chamber 12. This allows multiple electron beam emitters 10 to be stacked side by side to provide wide continuous electron beam coverage.

Referring to FIG. 2, filament 22a typically has a round cross section and is formed of tungsten. As a result, the major cross sectional area portion 34 is also a major diameter portion and the minor cross sectional area portion 36 is also a minor diameter portion. Usually, the major diameter portion 34 has a diameter that is in the range of .010 to .020 inches. The minor diameter portion 36 is typically sized to provide only 1° F to 2° F increase in temperature because such a small increase in temperature can result in a 10% to 20% increase in the emission of electrons e^-. The diameter of portion 36 required to provide a 1° F to 2° F increase in temperature relative to portion 36 is about 1 to 5 microns smaller than portion 34. The removal of such a small amount of material from portions 36 can be performed by chemical etching such as with hydrogen peroxide, electrochemical etching, stretching of filament 22a as depicted in FIG. 3, grinding, EDM machining, the formation and removal of an oxide layer, etc. One method of forming the oxide layer is to pass a current through filament 22a while filament 22a is exposed to air.

In one embodiment, filament 22a is formed with minor cross sectional area or diameter portions 36 at or near the ends (FIG. 2) so that greater amounts of electrons are generated at or near the ends. This allows electrons generated at the ends of filament 22a to be angled outwardly in an outwardly spreading beam 15 without too great a drop in electron density in the lateral direction. The widening electron beam allows multiple electron beam emitters to be laterally stacked with overlapping electron beams to provide uninterrupted wide electron beam coverage. In some applications, it may also be desirable merely to have a higher electron intensity at the ends or edges of the beam. In another embodiment where there is a voltage drop across the filament 22a, a minor cross sectional area or diameter portion 36 is positioned at the far or distal end of filament 22a to compensate for the voltage drop resulting in an uniform temperature and electron emission distribution across the length of filament 22a. In other embodiments, the number and positioning of portions 34 and 36 can be selected to suit the application at hand.

Referring to FIG. 4, filament 40 may be employed within electron beam emitter 10 instead of filament 22a. Filament 40 includes a series of major cross sectional area or diameter portions 34 and minor cross sectional area or diameter portions 36. The minor diameter portions 36 are formed as narrow grooves or rings which are spaced apart from each other at selected intervals. In the region 38, portions 36 are spaced further apart from each other than in regions 42. As a result, the overall temperature and electron emission in regions 42 is greater than in region 38. By selecting the width and diameter of the minor diameter 36 as well as the length of the intervals therebetween, the desired electron generation profile of filament 40 can be selected.

Referring to FIGs. 5 and 6, filament 50 is still another filament which can be employed with electron beam emitter 10. Filament 50 has at least one major cross sectional area or diameter 34 and at least one continuous minor cross sectional area 48 formed by the removal of a portion of the filament material on one side of the filament 50. FIGs. 5 and 6 depict the formation of minor cross sectional area 48 by making a flattened portion 48a on filament 50. The flattened portion 48a can be formed by any of the methods previously mentioned. It is understood that the flattened portion 48a can alternatively be replaced by other suitable shapes formed by the removal of material such as a curved surface, or at least two angled surfaces.

Referring to FIG. 7, filament 52 is yet another filament which can be employed within electron beam emitter 10. Filament 52 differs from filament 50 in that filament 52 includes at least two narrow minor cross sectional areas 48 which are spaced apart from each other at selected intervals in a manner similar to the grooves or rings of filament 40 (FIG. 4) for obtaining desired electron generation profiles. The narrow minor cross sectional areas 48 of filament 52 can be notches as shown in FIG. 7 or may be slight indentations, depending upon the depth. In addition, the notches can include curved angled edges or surfaces.

Referring to FIG. 8, filament 44 is another filament which can be employed within electron beam emitter 10. Instead of being elongated in a straight line as with filament 22a, the length of filament 44 is formed in a generally circular shape. Filament 44 can include any of the major and minor cross sectional areas 34, 36 and 48 depicted in FIGs. 2-7 and arranged as desired. Filament 44 is useful in applications such as sterilizing the side walls of a can.

Referring to FIG. 9, filament 46 is still another filament which can be employed within electron beam emitter 10. Filament 46 includes two substantially circular portions 46a and 46b which are connected together by legs 46c and are concentric with each other. Filament 46 can also include any of the major and minor cross sectional areas 34, 36 and 48 depicted in FIGs. 2-7.

Referring to FIG. 10, the structural metallic foil 32a of exit window 32 is typically formed of titanium, aluminum, or beryllium foil. The corrosion resistant high thermal conductive coating or layer 32b has a thickness that does not substantially impede the transmission of electrons e^- therethrough. Titanium foil that is 6 to 12 microns thick is usually preferred for foil 32a for strength but has low thermal conductivity. The coating of corrosion resistant high thermal conductive material 32b is preferably a layer of diamond, .25 to 2 microns thick, which is grown by vapor deposition on the exterior surface of the metallic foil 32a in a vacuum at high temperature. Layer 32b is commonly about 4% to 8% the thickness of foil 32a. The layer 32b provides exit window 32 with a greatly increased thermal conductivity over that provided only by foil 32a. As a result, more heat can be drawn from exit window 32, thereby allowing higher electron beam intensities to pass through exit window 32 without burning a hole therethrough than would normally be possible for a foil 32a of a given thickness. For example, titanium typically has a thermal conductivity of 11.4 W/m·k. The thin layer of diamond 32b, which has a thermal conductivity of 500-1000 W/m·k, can increase the thermal conductivity of the exit window 32 by a factor of 8

over that provided by foil 32a. Diamond also has a relatively low density (.144 lb./in.^{3}) which is preferable for allowing the passage of electrons e^- therethrough. As a result, a foil 32a 6 microns thick which would normally be capable of withstanding power of only 4 kW, is capable of withstanding power of 10 kW to 20 kW with layer 32b. In addition, the diamond layer 32b on the exterior surface of the metallic foil 32a is chemically inert and provides corrosion resistance for exit window 32. Corrosion resistance is desirable because sometimes the exit window 32 is exposed to environments including corrosive chemical agents. One such corrosive agent is hydrogen peroxide. The corrosion resistant high thermal conductive layer 32b protects the metal foil 32a from corrosion, thereby prolonging the life of the exit window 32.

Although diamond is preferred in regard to performance, the coating or layer 32b can be formed of other suitable corrosion resistant materials having high thermal conductivity such as gold. Gold has a thermal conductivity of 317.9 W/m·k. The use of gold for layer 32b can increase the conductivity over that provided by the titanium foil 32a by a factor of about 2. Typically, gold would not be considered desirable for layer 32b because gold is such a heavy or dense material (.698 lb./in^3) which tends to impede the transmission of electrons e^- therethrough. However, when very thin layers of gold are employed, .1 to 1 microns, impedance of the electrons e^- is kept to a minimum. When forming the layer of material 32b from gold, the layer 32b is typically formed by vapor deposition but, alternatively, can be formed by other suitable methods such as electroplating, etc.

In addition to gold, layer 32b may be formed from other materials from group 1b of the periodic table such as silver and copper. Silver and copper have thermal conductivities of 428 W/m·k and 398 W/m·k, and densities of .379 lb./in.^{3} and .324 lb./in.^{3}, respectively, but are not as resistant to corrosion as gold. Typically, materials having thermal conductivities above 300 W/m·k are preferred for layer 32b. Such materials tend to have densities above .1 lb./in.^{3}, with silver and copper being above

.3 lb./in.^{3} and gold being above .6 lb./in.^{3}. Although the corrosion resistant highly conductive layer of material 32b is preferably located on the exterior side of exit window for corrosion resistance, alternatively, layer 32b can be located on the interior side, or a layer 32b can be on both sides. Furthermore, the layer 32b can be formed of more than one layer of material. Such a configuration can include inner layers of less corrosion resistant materials, for example, aluminum (thermal conductivity of 247 W/m·k and density of .0975 lb./in.^{3}), and an outer layer of diamond or gold. The inner layers can also be formed of silver or copper. Also, although foil 32a is preferably metallic, foil 32a can also be formed from non-metallic materials.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

For example, although electron beam emitter is depicted in a particular configuration and orientation in FIG. 1, it is understood that the configuration and orientation can be varied depending upon the application at hand. In addition, the various methods of forming the filaments can be employed for forming a single filament. Furthermore, although the thicknesses of the foil 32a and conductive layer 32b of exit window 32 have been described to be constant, alternatively, such thicknesses may be varied across the exit window 32 to produce desired electron impedance and thermal conductivity profiles.